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10/646,509	08/22/2003	Brice A. Johnson	091-0185	9658
55397 7590 01/30/2007 INGRASSIA FISHER & LORENZ, P.C. 7150 E. CAMELBACK RD. SUITE 325 SCOTTSDALE, AZ 85251			EXAMINER AFTERGUT, JEFF H	
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Please find below and/or attached an Office communication concerning this application or proceeding.

C

Interview Summary	Application No.	Applicant(s)	
	10/646,509	JOHNSON ET AL.	
	Examiner	Art. Unit	
	Jeff H. Aftergut	1733	

All participants (applicant, applicant's representative, PTO personnel):

(1) Jeff H. Aftergut.

(3) Brice Johnson.

(2) Erin Madill.

(4) _____.

Date of Interview: 25 February 2007.

Type: a) ☒ Telephonic b) ☐ Video Conference
c) ☐ Personal [copy given to: 1) ☐ applicant 2) ☐ applicant's representative]

Exhibit shown or demonstration conducted: d) ☒ Yes e) ☐ No.

If Yes, brief description: copy of proposed claims, copy of translation of WO document.

Claim(s) discussed: proposed claims 38, 68.

Identification of prior art discussed: all.

Agreement with respect to the claims f) ☐ was reached. g) ☒ was not reached. h) ☐ N/A.

Substance of Interview including description of the general nature of what was agreed to if an agreement was reached, or any other comments: See Continuation Sheet.

(A fuller description, if necessary, and a copy of the amendments which the examiner agreed would render the claims allowable, if available, must be attached. Also, where no copy of the amendments that would render the claims allowable is available, a summary thereof must be attached.)

THE FORMAL WRITTEN REPLY TO THE LAST OFFICE ACTION MUST INCLUDE THE SUBSTANCE OF THE INTERVIEW. (See MPEP Section 713.04). If a reply to the last Office action has already been filed, APPLICANT IS GIVEN A NON-EXTENDABLE PERIOD OF THE LONGER OF ONE MONTH OR THIRTY DAYS FROM THIS INTERVIEW DATE, OR THE MAILING DATE OF THIS INTERVIEW SUMMARY FORM, WHICHEVER IS LATER, TO FILE A STATEMENT OF THE SUBSTANCE OF THE INTERVIEW. See Summary of Record of Interview requirements on reverse side or on attached sheet.

Examiner Note: You must sign this form unless it is an Attachment to a signed Office action.


Examiner's signature, if required

Summary of Record of Interview Requirements

Manual of Patent Examining Procedure (MPEP), Section 713.04, Substance of Interview Must be Made of Record

A complete written statement as to the substance of any face-to-face, video conference, or telephone interview with regard to an application must be made of record in the application whether or not an agreement with the examiner was reached at the interview.

Title 37 Code of Federal Regulations (CFR) § 1.133 Interviews

Paragraph (b)

In every instance where reconsideration is requested in view of an interview with an examiner, a complete written statement of the reasons presented at the interview as warranting favorable action must be filed by the applicant. An interview does not remove the necessity for reply to Office action as specified in §§ 1.111, 1.135. (35 U.S.C. 132)

37 CFR §1.2 Business to be transacted in writing.

All business with the Patent or Trademark Office should be transacted in writing. The personal attendance of applicants or their attorneys or agents at the Patent and Trademark Office is unnecessary. The action of the Patent and Trademark Office will be based exclusively on the written record in the Office. No attention will be paid to any alleged oral promise, stipulation, or understanding in relation to which there is disagreement or doubt.

The action of the Patent and Trademark Office cannot be based exclusively on the written record in the Office if that record is itself incomplete through the failure to record the substance of interviews.

It is the responsibility of the applicant or the attorney or agent to make the substance of an interview of record in the application file, unless the examiner indicates he or she will do so. It is the examiner's responsibility to see that such a record is made and to correct material inaccuracies which bear directly on the question of patentability.

Examiners must complete an Interview Summary Form for each interview held where a matter of substance has been discussed during the interview by checking the appropriate boxes and filling in the blanks. Discussions regarding only procedural matters, directed solely to restriction requirements for which interview recordation is otherwise provided for in Section 812.01 of the Manual of Patent Examining Procedure, or pointing out typographical errors or unreadable script in Office actions or the like, are excluded from the interview recordation procedures below. Where the substance of an interview is completely recorded in an Examiners Amendment, no separate Interview Summary Record is required.

The Interview Summary Form shall be given an appropriate Paper No., placed in the right hand portion of the file, and listed on the "Contents" section of the file wrapper. In a personal interview, a duplicate of the Form is given to the applicant (or attorney or agent) at the conclusion of the interview. In the case of a telephone or video-conference interview, the copy is mailed to the applicant's correspondence address either with or prior to the next official communication. If additional correspondence from the examiner is not likely before an allowance or if other circumstances dictate, the Form should be mailed promptly after the interview rather than with the next official communication.

The Form provides for recordation of the following information:

- Application Number (Series Code and Serial Number)
- Name of applicant
- Name of examiner
- Date of interview
- Type of interview (telephonic, video-conference, or personal)
- Name of participant(s) (applicant, attorney or agent, examiner, other PTO personnel, etc.)
- An indication whether or not an exhibit was shown or a demonstration conducted
- An identification of the specific prior art discussed
- An indication whether an agreement was reached and if so, a description of the general nature of the agreement (may be by attachment of a copy of amendments or claims agreed as being allowable). Note: Agreement as to allowability is tentative and does not restrict further action by the examiner to the contrary.
- The signature of the examiner who conducted the interview (if Form is not an attachment to a signed Office action)

It is desirable that the examiner orally remind the applicant of his or her obligation to record the substance of the interview of each case. It should be noted, however, that the Interview Summary Form will not normally be considered a complete and proper recordation of the interview unless it includes, or is supplemented by the applicant or the examiner to include, all of the applicable items required below concerning the substance of the interview.

A complete and proper recordation of the substance of any interview should include at least the following applicable items:

- 1) A brief description of the nature of any exhibit shown or any demonstration conducted,
- 2) an identification of the claims discussed,
- 3) an identification of the specific prior art discussed,
- 4) an identification of the principal proposed amendments of a substantive nature discussed, unless these are already described on the Interview Summary Form completed by the Examiner,
- 5) a brief identification of the general thrust of the principal arguments presented to the examiner,
(The identification of arguments need not be lengthy or elaborate. A verbatim or highly detailed description of the arguments is not required. The identification of the arguments is sufficient if the general nature or thrust of the principal arguments made to the examiner can be understood in the context of the application file. Of course, the applicant may desire to emphasize and fully describe those arguments which he or she feels were or might be persuasive to the examiner.)
- 6) a general indication of any other pertinent matters discussed, and
- 7) if appropriate, the general results or outcome of the interview unless already described in the Interview Summary Form completed by the examiner.

Examiners are expected to carefully review the applicant's record of the substance of an interview. If the record is not complete and accurate, the examiner will give the applicant an extendable one month time period to correct the record.

Examiner to Check for Accuracy

If the claims are allowable for other reasons of record, the examiner should send a letter setting forth the examiner's version of the statement attributed to him or her. If the record is complete and accurate, the examiner should place the indication, "Interview Record OK" on the paper recording the substance of the interview along with the date and the examiner's initials.

Continuation of Substance of Interview including description of the general nature of what was agreed to if an agreement was reached, or any other comments: discussed the use of multiple heads in the application and how each head was capable of independent movement relative not only to the surface of the mandrel but also for each head itself relative to the other heads. Noted that the WO document was making a blade or spar and that the reference did not envision use of anything other than specific robotic structures for the application of the material and did not envision the necessary heads to make a fuselage for an aircraft.

PROPOSED NEW CLAIMS:

38. (New) A device for fabricating a section of an aircraft fuselage via automated composite lamination on a mandrel surface, comprising:

a mandrel comprising a rotational axis and the mandrel surface, wherein the mandrel surface conforms to the section of the aircraft fuselage;

a mechanical supporting structure, wherein the mandrel is moveable and rotatable relative to said mechanical supporting structure; and

a plurality of material delivery heads supported by said mechanical supporting structure, wherein said mechanical supporting structure provides for movement of said plurality of material delivery heads relative to the mandrel surface during fabrication of the section of the aircraft fuselage, and wherein each of said plurality of material delivery heads is:

designed to apply composite material to the mandrel surface during fabrication of the section of the aircraft fuselage;

individually positionally adjustable relative to the mandrel surface and the other material delivery heads during application of the composite material by the material delivery heads during fabrication of the section of the aircraft fuselage; and

rotatable about an axis normal to the rotational axis during application of the composite material by the material delivery heads during fabrication of the section of the aircraft fuselage.

68. (New) A method for fabricating a section of an aircraft fuselage using a plurality of material delivery heads to apply composite materials on a mandrel surface of a mandrel having an axis, , wherein the mandrel is moveable and rotatable relative to said plurality of material delivery heads, and wherein the mandrel surface conforms to the section of the aircraft fuselage, the method comprising steps of:

applying, via the material delivery heads, composite material to the mandrel surface during fabrication of the section of the aircraft fuselage;

moving at least some of said material delivery heads relative to the mandrel surface during application of the composite material by the material delivery heads during fabrication of the section of the aircraft fuselage; and

individually adjusting positions of at least some of said material delivery heads relative to the mandrel surface and the other material delivery heads during application of the composite material by the material delivery heads during fabrication of the section of the aircraft fuselage; and

rotating at least some of said material delivery heads about an axis normal to the rotational axis during application of the composite material by the material delivery heads during fabrication of the section of the aircraft fuselage.

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Method for producing extruded profiles having a specific surface state made of fibre-reinforced synthetic resins, and machine for implementing the method

The present invention relates to a method for producing aerodynamic structures with a specific external surface state made of fibre-reinforced synthetic resins, said method being carried out with a machine for depositing fibres on such structures by coiling or by contact.

The following text contains terms or expressions that are defined as follows:

Thus, the term "tackifying agent" is understood to mean an agent or product enabling fibres to be fixed at least temporarily to one another and/or to a support. Such a tackifying agent may be a bonding agent or a resin.

The term "plies" is understood to mean a layer or a laminate of fibres, for example glass fibres.

The term "make-up" is understood to mean the number of layers of fibres, the thickness of each layer and the orientation of the layers.

The term "foamable resin" is understood to mean for example a resin that under certain conditions is converted into a foam so that it can fill empty spaces or cavities of a

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mould. An example of a foamable resin is expandable epoxy resin.

The term "continuous fibre" is understood to mean a fibre that is not divided up or cut up during its deposition on a mandrel or a support.

The term "discontinuous fibres" is understood to mean fibres that are divided up at precise points, so that they can adapt to the constraints of shapes and/or thickness of the deposited layers.

Aerodynamic structures with a specific external surface state made of fibre-reinforced synthetic resins are conventionally produced by contact moulding of woven materials or cores (rovings) in hollow moulds formed of two semi-shells, or on male moulds in a single envelope. The fibres are either already impregnated with resin and polymerised after deposition together with compacting, or are deposited dry, possibly with a tackifying agent, and then impregnated either manually by contact, or by infusion, transfer or injection of resin, using hollow counter-mould type tools or a flexible cover.

The techniques of moulding in hollow moulds formed of two semi-shells generally require a manual deposition of the woven materials, for the fabrication of the various elements of the external envelope and for the internal reinforcements, such as the internal partitions and the

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sandwich structures. Normally these elements are then trimmed, bonded and relaminated as a whole, cemented and polished in an entirely manual operation. The main disadvantages of this technique are on the one hand the need to have a large and skilled workforce, and on the other hand the fragility of the final product due to the bondings of the various elements forming the final profile. In addition, the losses of primary materials are large on account of the numerous cutting-up procedures.

The techniques of moulding in a single envelope on male moulds are either manual or are automated, in particular according to the automated fibre deposition technique involving coiling or by contact.

In the case of a manual implementation the fabricated pieces are generally of reduced size and the deposited fibres are not continuous, on account of the difficulty of handling and positioning the materials and the large size tools in a precise manner. Accordingly, the fabricated pieces do not have an optimum structure on account of the discontinuity of the fibres, and the size of the final product is limited.

Automated fibre deposition techniques by coiling or contact have often been proposed for fabricating the internal structure and/or external envelope of aerodynamic structures. These techniques automate the fibre and resin deposition phase, but do not allow sandwich-type structures to be formed without a manual deposition phase. In

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addition the core of these sandwich structures is in the form of sheets of constant thickness, which do not enable an optimum structure to be obtained having variable and specific thicknesses at each point of the envelope or of the internal partitions.

Another disadvantage of these automated techniques lies in their application for the fabrication of structures of large length. In fact, on account of the difficulty of manipulating or moving mandrels without causing serious deformations, the configuration of the currently used devices for automated deposition of fibres by coiling or by contact does not enable continuous fibres to be deposited in a precise way on an internal mould or movable mandrel, which may bend a few centimetres for lengths greater than 25 m.

The document EP 0 657 646 for example discloses a device and a method for producing aerodynamic structures, using longitudinal and cross-wise coils of fibres combined with a synthetic resin. Hollow cores or cores of rigid foam are introduced into the centre of the coils. Such a method does not *a priori* enable satisfactory mechanical properties to be obtained so as to produce aerodynamic structures of very large dimensions, in particular 25 m and above. In addition such a method does not enable laminates of large thickness, decreasing over the length of the structures, to be obtained.

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The documents FR 2 773 513, EP 0 225 563 and EP 0 680 818 describe machines and systems for the automated deposition of fibres by coiling or by contact for the fabrication of various large-size composite structures, in particular aerodynamic extruded profiles. These documents do not describe a way of depositing continuous fibres on large-size, movable mandrels or moulds, which may moreover bend several centimetres.

The documents WO 99/22932 and US 4 699 683 describe depositing machines and systems for fabricating various large-size composite structures, in particular aerodynamic structures, though the fibres are not continuous since the envelope is formed from two semi-shells which are then bonded together, which means that the final product is fragile.

A disadvantage of the existing machines and devices for the automated deposition of fibres by coiling or by contact is the low deposition rate of materials per unit time, with respect to the total amount of material to be deposited for the fabrication of large-size aerodynamic profiles. For example, the fabrication of a windpower blade 40 m long and weighing 10 tons would require a coiling and deposition time of 100 hours using a machine depositing 100 kg per hour.

Another disadvantage of the current machines and devices for the automated deposition of fibres is their high cost, since they generally consist of specific elements, such as

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carriages, shafts and mechanical linkages, which are made to measure and therefore expensive given the small numbers that are produced. Accordingly, the long fabrication times would not be economically viable on account of the hourly cost of such a machine, which could not be written off with such a low production rate.

Moreover, these designs of special types of machine are less reliable than machines produced from standard elements that have been tried and tested in numerous applications. Finally, their specific function, namely the deposition of fibres, means that they cannot be used to carry out other automated tasks such as surface treatment or machining.

The object of the present invention is accordingly to provide a method for producing aerodynamic structures that does not exhibit the disadvantages of the prior art and enables the mechanical features of the said structures to be improved.

Another object of the invention is to provide a method for producing aerodynamic structures enabling a specific surface state to be obtained and the maximum dimensions of the said structures to be increased, with moreover a reduction in production costs.

These objects of the present invention are achieved by means of a method for producing aerodynamic structures that extend in a longitudinal direction and in a transverse

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plane, by using an assembly of at least two mandrels and consisting in:

- a) producing a first deposit of fibres on each mandrel so as to coat each mandrel,
- b) compacting *in vacuo* the deposit of fibres and/or infusing a polymerisable resin into the said deposit,
- c) polymerising the first deposit,
- d) placing and supporting the coated mandrels in a hollow mould so as to delimit free spaces in the mould,
- e) injecting resin into the mould so as to fill at least part of the free spaces, in such a way as to form reinforcements in an envelope of the structure or in internal partitions of the said structure,
- f) polymerising the resin and the thereby formed assembly and removing the said assembly from the mould,
- g) producing a complementary deposit of fibres on the assembly obtained in stage f),
- h) arranging the assembly in a hollow mould and either repeating the stage b), or injecting resin into the hollow mould,
- i) polymerising the assembly and removing the obtained final structure from the mould,
- j) and carrying out a finishing treatment of the structure obtained in stage i).

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According to one embodiment, the method according to the invention consists during the stage e) in incorporating solid inserts into the free spaces and completing the injection of resin.

According to another embodiment, the method according to the invention consists during the stage e) in using foamable resin, the expansion of which in the structure and within a template arranged in the mould enables reinforcements to be formed in the said aerodynamic structure.

Other characteristics and advantages will likewise follow from the following detailed description given by way of example and with reference to the accompanying drawings, in which:

- Fig. 1 is a perspective diagrammatic view of an aerodynamic structure according to the invention;
- Fig. 2 is a perspective exploded diagrammatic view of the various internal and incorporated components of the structure of Fig. 1;
- Fig. 3 is a transverse sectional diagrammatic view along the line III-III of Fig. 1, of an aerodynamic structure according to the invention;
- Fig. 3a is an enlarged detail of Fig. 3;
- Fig. 4 is a transverse sectional diagrammatic view along the line IV-IV of Fig. 1, of an aerodynamic structure according to the invention;

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- Fig. 4a is an enlarged detail of Fig. 4;
- Fig. 5 is a perspective diagrammatic view of the first deposition stage by coiling and/or contact of fibres on a mandrel;
- Fig. 6 is a perspective diagrammatic view of a vertical machine for the production of large-size blades during a second stage of deposition of fibres on the aerodynamic structure;
- Fig. 7 is a perspective diagrammatic view of a vertical machine for the production of large-size blades during the dismounting of the profile after the second fibre deposition stage;
- Fig. 8 is a transverse sectional diagrammatic view of the hollow mould in which a template is placed in order to define the dimensions and an internal surface state during a foam injection and expansion stage in the core;
- Fig. 9 is a perspective exploded diagrammatic view of the mandrels and of the incorporated elements positioned in the hollow mould with a template;
- Fig. 10 is a transverse sectional diagrammatic view along the line X-X of Fig. 9 of the mandrels and of the incorporated elements in the hollow mould with a template after the expansion and polymerisation phase of the resin;
- Fig. 11 is a perspective diagrammatic view of the removal of three mandrels from the structure obtained after the injection and polymerisation of the resin;
- Fig. 12 is a perspective diagrammatic view of the incorporated elements bonded to the structure;

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- Fig. 13 is a perspective diagrammatic view of a second stage of deposition by coiling and/or compact of fibres on the structures;
- Fig. 14 is a transverse sectional diagrammatic view along the line X-X of Fig. 9 of the structure in the hollow mould with the injected resins;
- Fig. 14a is an enlarged detail of Fig. 14;
- Fig. 15 is a perspective diagrammatic view of the operation involving removal of the mandrel from the finished structure.

By way of example one embodiment of the object of the invention is described hereinafter and illustrated diagrammatically in Figs. 1 to 15, in which are shown three orthogonal directions L, T and E. The longitudinal direction, called L, corresponds to the axis of rotation of a machine for depositing fibres and to the axial direction of the foot of the blade (the part that is to be fixed to the external element such as the boss of the rotor) at its free end. A transverse direction, called T, is orthogonal to the direction L and is situated in a horizontal plane passing through L. An elevation direction E is orthogonal to both the directions L and T.

The following description provides an understanding of how an aerodynamic structure according to the invention is produced, such as a blade 1 of a windpower machine shown in a perspective diagrammatic view in Fig. 1, and the new performances that are thereby achieved.

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Before any production, a study carried out at the design stage provides details of the shape of the profile to be produced and the various constraints and stresses to which it will be subjected. One part of this study defines the thickness and the number of laminations, the orientation of the fibres in the different parts of the profile, as well as the orientation, the dimensions and the locations of the internal partitions and possible sandwich structures.

Fig. 2 shows a perspective exploded diagrammatic view of the different internal components 2, 3, 4, 5, 6, 7, provided for example for the production of the blade 1. The internal components thus comprise solid or hollow mandrels 2, 3, 4, 5, an incorporated piece 6, and a free end 7.

The blade 1 comprises a foot 8 intended to be mounted on a windpower rotor and an elongated part 9 of sandwich structure.

Fig. 3 is a sectional diagrammatic view of the structure along the line III-III of Fig. 1, with a structure composed of an envelope 10, the function of which is to create the desired aerodynamic force, and internal partitions 11 that provide the necessary strength and rigidity.

Laminates 12 and 13 consisting of plies oriented approximately in the direction L and of decreasing

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thickness from the foot 8 of the blade to its free end, work under traction and compression and absorb the flexural stresses mainly due to the aerodynamic pressure and to a lesser extent the intrinsic weight of the blade.

It can be seen in Fig. 3 that the laminates 12 and 13 are grouped in regions remote from the neutral planes close to the planes represented by L, T and E, L, so as to increase the moments of inertia of the blade with respect to the principal stresses.

Laminations 14 and 15 shown for example in Fig. 3a and covering the mandrels 2, 3, 4, and 5 consist for example in an amount of 80% of plies oriented at $\pm 45^\circ$, 10% of plies oriented at 90° , and 10% of plies oriented at 0° with respect to the direction L. The laminates 14 and 15 mainly absorb the shear stresses between the laminates 12 and 13, the local stresses due to the external pressure on the envelope 10, and the torsional stresses.

The blade 1 also contains locally foam 16, obtained for example from a foamable resin, of variable thickness, contributing inertia to the envelope 10 and to the internal partitions 11 so as to limit the thickness of the laminations 14 and 15. It is envisaged that, in the case of three partitions 11, the number of $\pm 45^\circ$ and 90° plies of the lamination 14 should be identical at the level of the partitions 11 and at the level of the envelope 10. It is also envisaged that the number of $\pm 45^\circ$ and 90° plies of the laminate 14 at the level of the partitions 11 should be

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identical to the number of $\pm 45^\circ$ and 95° plies of the laminate 15 at the level of the envelope 10. One may therefore have, at the level of the partitions 11 and laminates 14, states of symmetry as regards the numbers of plies.

It is also envisaged that the number of 0° plies of the laminates 14 and 15 is identical at the level of the envelope 10. It is furthermore envisaged that the arrangement and the number of the plies of the laminates 14 and 15 are defined so as to obtain a symmetrical structure on all sides of the foam 16 at the level of the partitions 11 and of the envelope 10.

Fig. 4 is a sectional diagrammatic view of the foot part 8 of the blade 1 along the line IV-IV of Fig. 1 with a structure consisting of the envelope 10, the function of which is to transmit the connection stresses to an external element, such as the rotor of a windpower machine, and the part 9 at the foot 8 shown in Fig. 2. The number of laminates 13 is larger at the foot 8 than at the part 9, the laminates being uniformly arranged around a cylindrical profile so as to distribute the main stresses at the points of securement of the blade 1, covering the plies of the laminates 14 deposited over the whole length of the blade 1. The laminates are covered by the plies of the laminates 15 over the whole length of the blade 1. The high torsional and flexural stresses and high shear and buckling forces are also distributed by an additional lamination 17 at the foot 8 (consisting of plies approximately

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equilibrated $\pm 45^\circ$, 90° and 0° with respect to L) having a thickness decreasing from the foot 8 to the part 9.

The total thickness of these laminations 13, 14, 15, 17 is sufficient to ensure the rigidity of the envelope 10 at the foot 8, and no foamed core 16 is required as is provided for in the part 9, the thickness of which becomes vanishingly small from the part 9 to the part 8.

It is found that the orientation, the continuity and the arrangement of the plies of the different laminations thereby obtained satisfactorily meet the constraints of shape, strength and rigidity of a blade 1 of a windpower machine, and what is more can be produced by the method and with the machine described hereinafter. The thickness of each ply as well as the number of internal partitions 11 (which can be zero) can easily be calculated and adapted depending on the size of the aerodynamical structure, materials used and assumptions concerning envisaged loads.

Fig. 5 is a perspective diagrammatic view which illustrates the first deposition stage by coiling and/or contact of fibre on the mandrel 3, using a machine 19 on which all the stages of the method described hereinafter can be carried out. This machine 19 consists of standard elements and units, such as robots 20 on which various systems may be mounted, such as a deposition head 21 involving coiling and/or contact of fibres, and a machining or projection head. The number of these robots 20 may vary, the robots being mounted on linear axes 22, and the mandrel 3 is

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caused to rotate by means of a positioner at 23 and a tailstock 24. Depending on the size of the structure to be produced, and also on the amount of material to be deposited or machined, the machine 19 may be horizontally configured as shown in Fig. 5, or may have a vertical configuration as shown diagrammatically in Fig. 6. This figure shows a plate 24 with a lifting and guidance system 25, using the standard solutions of conventional goods lifts such as cables or screw jacks with a counterweight, which enables more than two robots 20 to be installed so as to deposit simultaneously more material by coiling and/or contact. This vertical configuration enables the problem of the flexion of the mandrel 3 to be suppressed and also reduces the risk of dislocation of material or plies during the rotation of the mandrel. In the two configurations, a coder measuring the speed and the position of the positioner 23 in the vertical or horizontal axis controls the plate 24 or carriages 20a, which themselves have their own coding system and support the robots 20 independently of one another.

The mounting and dismounting of the mandrels and structures is carried out in the case of the vertical machine 19 with the aid of the positioner 23, which tilts the extruded profile at the level of the foot, as shown in Fig. 7. The axis of rotation is provided so that the structure is in a favourable position, that is to say in order to limit its bending during the tilting, for example about the axis E. In the case of a horizontal machine 19, the mounting and dismounting of the blade 1 is carried out in a conventional manner.

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The internal and external dimensions of the blade 1 being known, internal moulds, for example four mandrels 2, 3, 4, 5, the external dimensions of which correspond to the internal dimensions of the four components 2a, 3a, 4a and 5a of the blade 1, and a hollow mould 26, the internal surface of which corresponds to the external dimensions of the blade 1 to be produced, were fabricated according to the conventional techniques. They can also consist entirely or in part of inflatable or flexible elements, in the case where the shape does not allow them to be removed after polymerisation due to the fact that the shapes are such that they cannot be removed from the mould, or in the case of clearances that are too small over large lengths. In addition, in one embodiment they may allow the different plies covering them to be compacted.

A first mandrel 3 corresponding for example to the internal shape of the element 3a is mounted on the machine 19 in order if necessary to undergo a refining treatment of its external surface, such as the application of a mould release agent and a tackifying agent by a spray system mounted at the end of the robots 20, and if necessary the insertion of wedges (not shown) at the ends of the mandrel 3.

Once this preparatory stage has been completed, the automatic deposition of fibres by coiling and/or contact is carried out so as to obtain the make-up defined during the design stage, by means of heads 21 for depositing fibres by

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coiling or by contact, such as are found in industry and that enable fibres, for example continuous or discontinuous fibres consisting of pre-impregnated coves, to be placed in position and bonded, the said heads being mounted at the ends of the robots 20. This fibre deposition by coiling and/or contact starts for example with the plies of the laminates 14 at 45° and -45° , 88° and -88° , and 0° with respect to the direction L and continues between the two ends of the mandrel 3, as is shown in Fig. 5. The 0° plies of the laminates 12 or 13, depending on the mandrel that is covered, are then deposited longitudinally in the direction L, while progressively reducing the number of layers of the zone from the foot 8 of the blade 1 to its free end, that is to say by interrupting the deposition at intermediate zones between the two ends. The three other mandrels 4, 5, 6 then undergo the same treatments and all four are polymerised according to the known techniques, for example in vacuo at a temperature of 80°C .

In parallel to this a hollow mould 26 intended for the formation of the foam core is prepared. For example, as is shown in Fig. 8, this mould 26 may be formed in two parts, the internal dimensions of which correspond to the final external dimensions of the blade 1, in which mould is placed a two-part template 27, for example of composite material of suitable thicknesses so that its dimensions and its internal surface state can adapt to the expansion stage of the foam core 16. The volume of this two-part template 27 corresponds to the fibres and to the resin that will be deposited in a second phase, with their specific thickness at each point. In order to ensure a good bonding of the

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adhesive that will be carried out with the laminates 15 and 17, the internal surface state of this template 27 has an adequate roughness, which may require the deposition of a mould release agent before injecting or depositing resin.

During the positioning of the four mandrels 2, 3, 4 and 5 covered with their laminates 12, 13 and 14 in the mould 26 and the template 27, elements, such as the end 7 forming part of the blade 1, may be attached as shown in Fig. 9. The end 7 may be formed for example in a conventional way of fibres with an injection of resin. The exterior of this end 7 has a smooth surface at the definitive external dimensions of the blade 1 and the interior has a rough surface in order to ensure a good bonding on the laminates 12, 13 and 14 covering the mandrels 2, 3, 4 and 5. Other reinforcements and/or fibres and/or inserts such as lightning conductors may be arranged in the mould 26 and the template 27 so as to be impregnated or bonded by the foamable resin. A handling and adjustment system 31 enables the set of mandrels to be positioned in the mould 26 and the template 27 so as to maintain them at a given distance from the internal wall of the said mould 26 and between the mandrels 2, 3, 4, 5. This distance is specific to each part of the envelope 10 and the three partitions 11 of the blade 1, and corresponds to the variable thickness of the foam reinforcements 16 provided for at the design stage.

Fig. 10 shows diagrammatically and in a transverse section along the line x-x of Fig. 9, the mandrels 2, 3, 4 and 5

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covered by their laminates 12, 13 and 14 in the mould 26 together with the template 27, after the expansion phase of the foamable resin 26 which was previously inserted and/or injected, possibly in successive stages. This foamable resin may for example be epoxy resin with a foaming agent which enables the density of the polymerised foam to be reduced. The resultant foam 16 ensures on the one hand a bonding between the four mandrels 2, 3, 4, 5, and on the other hand provides a structural reinforcement.

Fig. 11 is a perspective diagrammatic view of the operation involving the removal (in the removal direction R) of the three mandrels 2, 4 and 5 of the structure 32 obtained after the polymerisation of the foamable resin, with the mould 26 preferably sealed in order to block the said structure 32 during the removal. The mandrel 3 is left in place in order to manipulate the resultant structure 32 and maintain the same position references during the next stages of the process. During the design stage of the blade 1 and mandrel 3, the centres of gravity of the arrangement consisting of the mandrel 3 and the resultant structure 32, which is subsequently covered by the laminates 15 and 17, were calculated to be as close as possible to the axis of rotation of the positioner 23 of the machine 19, so as to limit the imbalances during the next stages involving deposition of plies.

The structure 32 together with its mandrel 3 is then removed from the mould of the template 27. Inserts may be installed and bonded in place, such as the element 6 shown

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in Fig. 12. The structure 32 is then manipulated on one side by means of the end of the mandrel 3, and on the other side by means of a conformer (device preventing deformation) 33, which holds the whole arrangement by the finished end 7 and positions it on the axis of the positioner 23 of the machine 19 during the next stages of the process, as can be seen in Fig. 13. A new stage involving deposition of plies may also be carried out.

Before this deposition the structure 32 may if necessary undergo on the machine 19 a refining treatment of its external surface, such as the insertion of a tackifying agent by a spray system mounted at the end of the robots 20 and/or a deflashing of the parting lines of the foamable resin by means of a machining system mounted at the end of the robots 20. Once this preparatory stage has been completed, the automatic deposition of fibres is carried out so as to obtain the make-up defined during the design stage, by means of the heads 21 for depositing fibres by coiling and/or contact, mounted at the ends of the robots 20, as shown in Fig. 13. This stage starts for example with the deposition of the plies of the laminates 15 and 17. The number of layers is reduced progressively from the foot 8 of the blade to its other end, by chopping the fibres in intermediate zones between the two ends.

The plies of the fibres of the laminates 15 and 17, pre-impregnated for example with a tackifying agent in order to keep them on the structure 32, may then be impregnated by an injection of resin. In this case it is envisaged during

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the deposition of fibres to leave adequate gaps between each group or tuft of fibres in certain parts and/or layers, so as to facilitate the transfer of resin during the injection. These gaps may be obtained by adjusting, on the heads 21 for depositing fibres by coiling and/or contact, the spacing of the pulleys or combs for guiding the tufts of fibres, or by means of closer tufts that do not abut at the outlet of the heads 21. Also, drainage materials such as felts in the form of strips may be applied between the layers.

In parallel to this the hollow mould 26, the internal dimensions of which correspond to the final external dimensions of the blade 1, was formed with the removal of the template 27 and if necessary with the addition of a mould release agent and a thermoplastic or thermosetting film intended to protect and colour the external surface of the blade 1. The structure 32 covered by the laminates 15 and 17 is then placed in the mould 26 so as to effect a transfer of resin, for example by means of an assisted injection *in vacuo*. Inserts, such as a vent 34, may be incorporated. Figs. 14 and 14a are transverse sectional diagrammatic views along the line x-x of Fig. 9 of the final structure 35 obtained once the resin has been injected and polymerised, which corresponds to the end shape of the blade 1, with the mould 26 and mandrel 3 remaining in place.

This final structure 35 is then removed from the mould 26 so that it can be mounted on the machine 19, with the

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conformer 33 and the mandrel 3, which enable the position references to be maintained. The final structure 35 may then undergo a finishing treatment such as a deflashing of parting lines, cutting into sections for the assembly of inserts for fixing the profile to an external element, and a painting operation by installing suitable equipment on the robots 20, such as a spray gun or a cutting and milling spindle.

The final structure 35 is then dismounted from the machine 19 and the mandrel 3 is removed in the direction of the arrow R, as shown in Fig. 15. This final structure 35 corresponds to the blade 1, which is now ready to receive inserts such as securement collar so that the blade can be mounted on the rotor of a windpower machine.

According to one embodiment, the method according to the invention comprises the steps involving:

- mounting the structure with the machine on a longitudinal mandrel 2, 3, 4, 5 corresponding to the internal shape of the structure, or on a plurality of mandrels corresponding to the longitudinal internal cavities of the structure in the case where it comprises longitudinal internal partitions 11, wedges and/or anti-slip products, enabling the adherence between the mandrel or mandrels 5 and the fibres that will cover it, to be improved;
- depositing on the mandrel or mandrels by coiling and/or contact, with the machine, dry fibres or fibres impregnated with resin or tackifying agent in directions

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and thicknesses defined during the design stage of the aerodynamic structure 32,

- subjecting to pressure the materials deposited on the mandrel or mandrels 2, 3, 4, 5, with a compaction under vacuum with the aid of a cover and/or carrying out an infusion of resin under cover and polymerising the resin,

- placing this mandrel or these mandrels 2, 3, 4, 5 covered with materials in the hollow mould 26 and immobilising them so as to keep them at a given distance from the internal wall of the hollow mould 26 and from one another if there are several moulds, injecting foamable or non-foamable resin into the whole of the free space corresponding to the thickness of the foam reinforcements 16 provided for in each part of the envelope 10 and of the possible internal partitions 11 of the final structure,

- after polymerising the foam, leaving a solid or hollow mandrel in place so as to maintain the centre of gravity of the resultant piece, covered subsequently with another layer of fibres, as close as possible to the axis of rotation of the positioner of the machine, removing the possible other mandrels 2, 4, 5, and removing the arrangement thereby obtained from the hollow mould 26,

- mounting this arrangement on the machine and depositing on this arrangement by coiling and/or contact with the machine, dry fibres or fibres impregnated with resin or tackifying agent in directions and thicknesses defined during the design stage of the aerodynamic structure 32,

- subjecting to pressure the materials arranged in the external hollow mould 26, the internal surface of which

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corresponds to the external shape of the profile, so as to obtain an external surface state identical to that of the internal surface of the hollow mould 26 and a defined amount of resin, by an injection of resin and/or an expansion of resin such as foamable resin, and/or by increasing the volume of the mandrel or mandrels, or subjecting to pressure the materials by a compaction in vacuo with the aid of a cover and/or an infusion of resin with the aid of a cover,

- after polymerisation, removing the profile obtained from the hollow mould 26 or from the cover and mounting it on the machine so as to undergo a refining treatment and/or finishing treatment such as deflashing, painting and cutting into sections, for example for the passage or assembly of inserts for fixing the structure to an external element, and/or for the removal of the mandrel 3.

The production method and the aerodynamic structures obtained by such a method have major advantages:

The production is entirely automated thanks to the use of the design software, calculations by finite elements, simulation of deposition of fibres, and digital control programming. The machine for depositing fibres is an automated machining, spraying, winding and sectioning unit. Accordingly, the risk of non-conformity is limited, on the one hand thanks to the automation which guarantees the reproducibility of the fabricated product, and on the other hand thanks to the implementation of the various operations

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using the same robots and mounting unit, thereby improving the geometrical accuracy of the final structure.

The core of the sandwich structure produced by an expansion of foamable resin has the advantage, compared to the conventional bonding of plates, that it enables the production time to be reduced, guarantees a perfect bonding with the external and internal skins, and enables an optimum thickness to be obtained that changes at each point of the structure, thereby optimising the amount of material and the weight.

The finished product has good mechanical properties, due on the one hand to the automatic deposition procedure which enables the fibres to be deposited in optimum alignments/orientations, and on the other hand to the maximum content of continuous fibres, without in particular having to make a cut between the upper face and lower face of the blade.

The positioning of the inserts is much more precise thanks to an automated machining.

The conventional structures, such as laminates whose thickness decreases over the length of the structures as well as the foamed cores of variable thickness over a specific length of the profile, can be achieved by means of the various stages involving deposition of fibres and the various techniques for impregnation and injection of resin.

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The maximum dimensions of the achievable structures are increased thanks to the vertical design of the fibre deposition machine, enabling larger windpower blades to be produced.

The realisation of the machine for implementing the method according to the invention from standard elements and units provides a high degree of reliability and a reduced overall cost compared to the existing machines.

The production outputs are increased thanks to the plurality of fibre deposition heads, which increase the amount of material deposited per hour, and in addition the losses of material are virtually zero.

Moreover, the external surface may be smooth or rough depending on the requirements.

Finally, the method that is the subject-matter of the invention is particularly adapted to the large-scale production of windpower blades and various aerodynamic structures such as wings and masts.

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CLAIMS

1. Method for producing aerodynamic profiles (32, 35) extending in a longitudinal direction (L) and a transverse direction (T) and in an elevation direction (E), using an assembly of mandrels (2, 3, 4, 5) and consisting in:
- a) producing a first deposit of fibres on each mandrel (2, 3, 4, 5) so as to coat each mandrel (2, 3, 4, 5),
 - b) compacting in vacuo the deposit of fibres and/or infusing a polymerisable resin into the said deposit,
 - c) polymerising the first deposit,
 - d) placing and supporting the coated mandrels (2, 3, 4, 5) in a hollow mould (26) so as to delimit free spaces in the mould,
 - e) injecting resin into the mould so as to fill at least part of the free spaces, in such a way as to form reinforcements in an envelope (10) of the structure (32) or in internal partitions (11) of the said structure (32),
 - f) polymerising the resin and the thereby formed assembly and removing the said assembly from the mould,
 - g) producing a complementary deposit of fibres on the assembly obtained in stage f),
 - h) arranging the assembly in a hollow mould (26) and either repeating the stage b), or injecting resin into the hollow mould (26),

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- i) polymerising the assembly and removing the obtained final structure (35) from the mould,
- j) and carrying out a finishing treatment of the structure (35) obtained in stage i).

2. Method according to claim 1, characterised in that it consists, in the stages (a) and (g), of carrying out the depositions of fibres by contact and/or by coiling.

3. Method according to claim 1 or 2, characterised in that it consists, in the stages (a) and (g), of depositing dry fibres or fibres impregnated with a resin or a tackifying agent.

4. Method according to any one of claims 1 to 3, characterised in that it consists in using solid or hollow mandrels (2, 3, 4, 5), at least one of which is removed from the arrangement following the stage (f), and in which the last mandrel (3), or part of this mandrel, serving as a support in the stages (g), (h), (i) and (j), is removed from the aerodynamic structure (35) after the stage (j).

5. Method according to any one of claims 1 to 4, characterised in that it consists in using a single mould (26) to carry out the moulding stages in (d) and (h), and in arranging a template (27) in the said mould for the stage (d) so as to define the shape of the arrangement after injection of resin during the stage (e).

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6. Method according to any one of claims 1 to 5, characterised in that it consists in the stage (e), of integrating into the free spaces solid inserts to complement the injection of resin.

7. Method according to claim 5 or 6, characterised in that it consists during the stage (e) of using foamable resin, the expansion of which in the structure (32) and in the interior of the template (27) enable reinforcements to be formed in the aerodynamic structure (32).

8. Method according to any one of claims 1 to 7, characterised in that it consists in forming, during the first deposition of fibres, plies oriented substantially in the longitudinal direction (L) of the aerodynamic structure (32), complementing the plies intended to coat the mandrels.

9. Method according to claim 7, characterised in that it consists in injecting the foamable resin between the laminates (12, 13, 14, 15) of plies having an identical make-up so as to obtain a symmetry of the envelope (10) and of the internal partitions (11) with respect to the number of plies.

10. Method according to any one of claims 1 to 9, characterised in that it consists in depositing, during the first deposition, in stage (a), at least one of the plies

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of continuous fibres and of the plies of discontinuous fibres.

11. Aerodynamic structure, characterised in that it is produced by the method according to any one of claims 1 to 10.

12. Blade for a windpower machine, characterised in that it is produced by the method according to any one of claims 1 to 10.